The Modal-Vertical-Beam(MVB) Transmission Loss Analysis

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Main Scientific Objective

•**Extraction the beam-averaged modal attenuation coefficient d_n**

How to do?

Step 1: Perform vertical plane wave beamforming with VLA acoustic data

Step2: Estimate the beamformer output spectrum

Step3:Calculate propagation loss of two different ranges

Step4: Extract the beam-averaged modal attenuation coefficient from propagation loss

Why to do?

Be important for bottom back-scattering matrix extraction from reverberation data as well as propagation modeling

Theory Frame

The complex pressure in a range-independent waveguide can be written as:

$$p(r, z_j, z_s, w) = \sum_{n=0}^{N-1} a_n(r) j_n(z_j) j_n(z_s) \exp\left[-i\left(wt - k_n r + p/4\right) - d_n r\right]$$

For an ideal spatial filter response, the beamformer output can be written as:

$$b(r, \bar{\gamma}, z_s, \omega) = \sum_{\bar{m}-\Delta m/2}^{\bar{m}+\Delta m/2} a_n(r) \varphi_n(z_s) \exp\left[-i\left(\omega t - k_n r + \pi/4\right) - \delta_n r\right]$$

The vertical beamformer output spectrum is

$$B(r, \gamma_n, z_s, \omega) = \sum_n a_n^2(r) \varphi_n^2(z_s) \exp(-2\delta_n r)$$

$$+2 \sum_n \sum_{\substack{m \\ n \neq m}} a_n(r) a_m(r) \varphi_n(z_s) \varphi_m(z_s) \exp\left(-(\delta_n + \delta_m) r\right) \cos\left(\Delta k_{nm} r\right)$$

$$= B_1 + B_2$$

Theory Frame(continued)

If $B_2 \ll B_1$, the beamformer output spectrum is written as:

$$B(r,\gamma_n,z_s,\omega)=\sum_n a_n^2(r)\varphi_n^2(z_s)\exp(-2\delta_n r)$$

We define the beam-averaged modal attenuation as follow:

$$\exp(-2\delta_{\overline{m}}r)=\sum_{\overline{m}-\Delta m/2}^{\overline{m}+\Delta m/2} a_n^2(r)\phi_n^2(z_s)\exp(-2\delta_n r)\Bigg/\sum_{\overline{m}-\Delta m/2}^{\overline{m}+\Delta m/2} a_n^2(r)\phi_n^2(z_s)$$

Beam-averaged modal attenuation coefficient can be extracted by calculating the propagation loss for two ranges:

$$\delta_n=\frac{\log(tl(r_1,r_2))}{2(r_2-r_1)}$$

Where,

$$tl(r_1,r_2)=\frac{B(r_1,\gamma_n,z_s,\omega)\times r_1}{B(r_2,\gamma_n,z_s,\omega)\times r_2}$$

Numerical Simulation

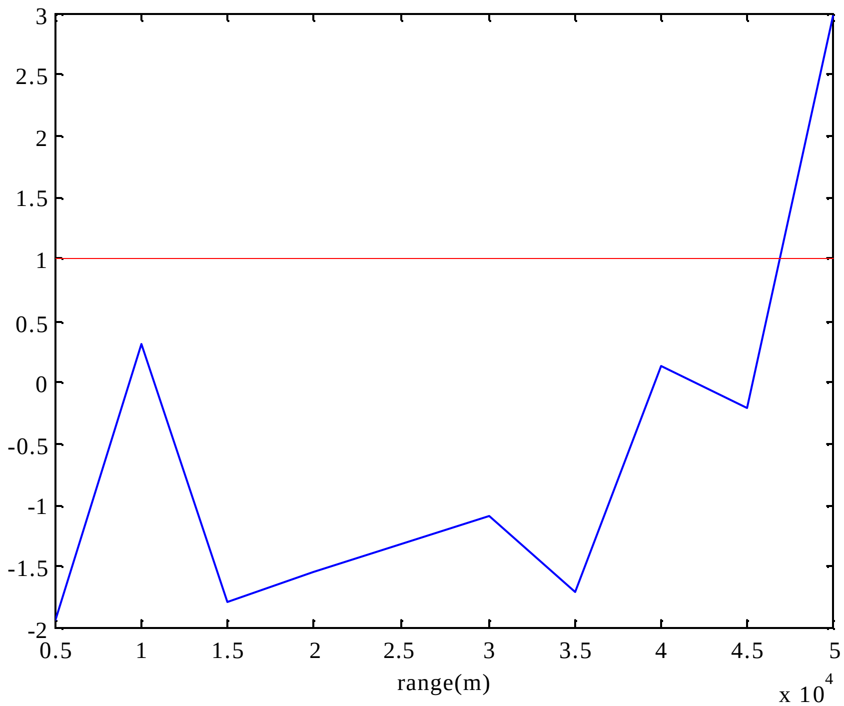
We consider a Pekeris waveguide : H=103m, C_0=1519m/s, C_b=1623m/s, $?_b$=1.72, a_b=0.49 dB/m·kHz, f=1390Hz. The 103m VLA is covered all depth of water column with 1m space of adjacent element.

Table 1 Theoretical value and calculated value of δ_n in Pekeris waveguide (f=1390Hz)

group	Center grazing angle	Group of modes	Theory value of δ_n	Calculated value of δ_n	
				r1=10km,r2=20km, zs=20m	r1=10km,r2=20km, zs=40m
1	2.3¡ã	1-8	3.367554e-6	-5.030152e-6	3.158571e-6
2	6.8¡ã	9-16	2.051041e-5	3.249568e-5	1.507090e-5
3	11.5¡ã	17-24	5.064872e-5	3.641855e-5	5.898481e-5
4	16.2¡ã	25-32	9.020034e-5	9.085626e-5	8.014695e-5

Due to the effect of intermode interference , δ_n of group 1 can not be estimated correctly, and the precisions of estimated δ_n of other groups are poor.

Numerical Simulation(continued)



Effects of intermode interference can not be ignored

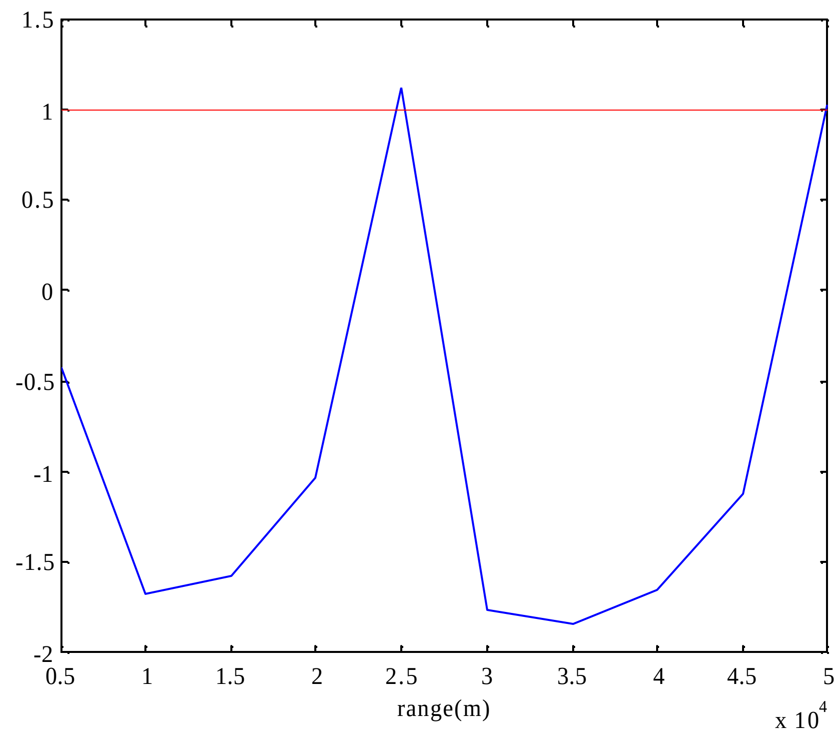


Fig.1 Effect of intermode interference (f=1390Hz, z_s=20m)

Fig.2 Effect of intermode interference (f=1390Hz, z_s=40m)

Numerical Simulation(continued)

How can we reduce the effects of intermode interference? One method is averaged the beamformer output spectrum with f in a narrow band to smooth second item B_2.

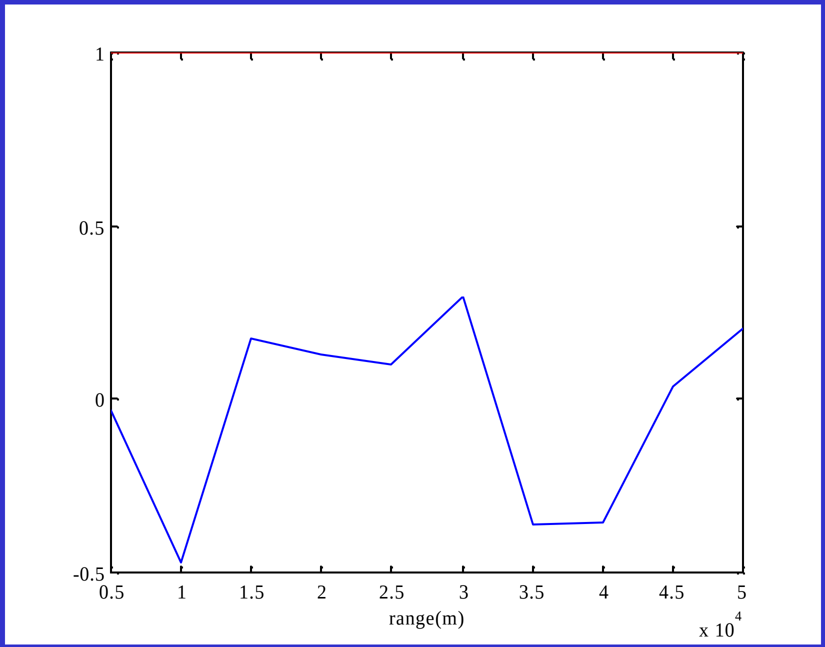


Fig.3 Effect of intermode interference (f=1340-1440Hz, z_s=20m)

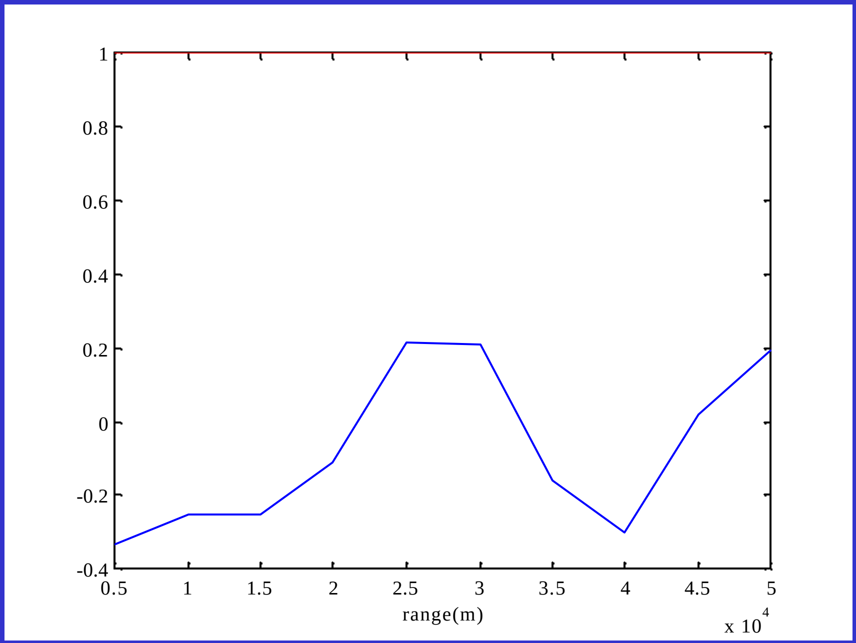


Fig.4 Effect of intermode interference (f=1340-1440Hz, z_s=40m)

Numerical Simulation(continued)

Table 2 Theory value and calculated value of δ_n in Pekeris waveguide (f=1340-1440Hz)

group	Center grazing angle	Group of modes	Theory value of δ_n	Calculated value of δ_n		
				r1=5km, r2=10km, zs=40m	r1=10km, r2=20km, zs=40m	r1=10km, r2=20km, zs=20m
1	2.3¡ ã	1-8	3.143104e-6	7.894265e-6	1.705594e-6	3.646730e-6
2	6.8¡ ã	9-16	1.918959e-5	1.920825e-5	2.095787e-5	1.802004e-5
3	11.5¡ ã	17-24	4.754961e-5	4.799638e-5	4.731562e-5	4.815836e-5
4	16.2¡ ã	25-32	8.491166e-5	8.500221e-5	8.566655e-5	8.432893e-5

Compared to Table 1, the attenuation coefficients of all groups can be estimated, the precision is also improved effectively.

Numerical Simulation(continued)

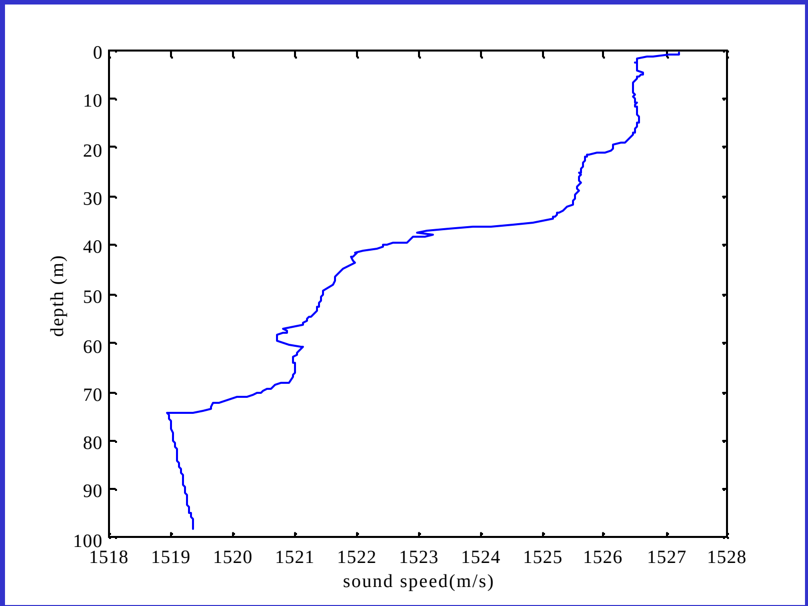


Fig. 5 SVP of ECS

All the calculated d_n are larger than the theoretical values. This is due to:

(1) effect of inter mode interference

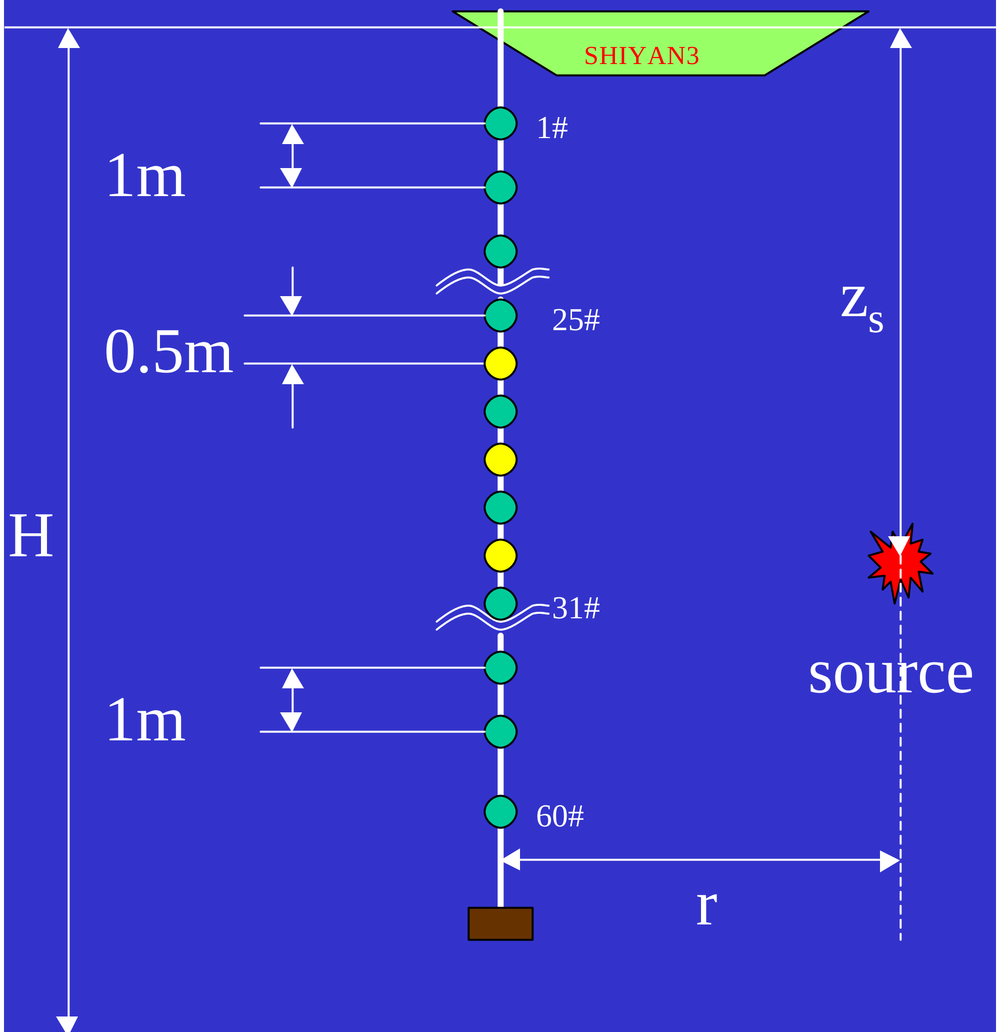
(2) the short VLA covered the upper half part of the water column is not able to capture the lower modes properly and affected by higher modes by leakage.

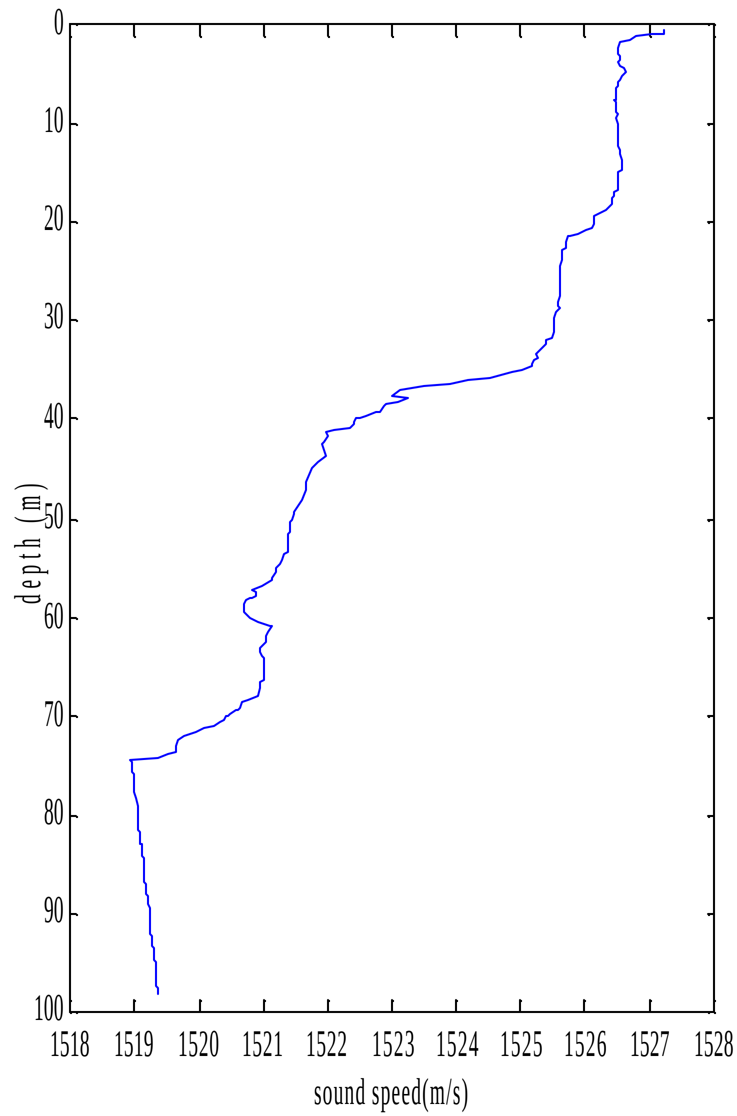
Table 3 Theoretical value and calculated value of δ_n in simulated shallow waveguide (f=1340-1440Hz)

group	Center grazing angle	Group of modes	Theory value of δ_n	Calculated value of δ_n	
				r1=10km,r2=20km, zs=40m, 103mVLA	r1=10km,r2=20km, zs=40m,57mVLA
1	2.3¡ ã	1-8	6.011310e-6	2.193981e-5	1.630264e-5
2	6.8¡ ã	9-16	2.272945e-5	3.075102e-5	4.356382e-5
3	11.5¡ ã	17-24	3.601585e-5	5.283101e-5	6.074829e-5
4	16.2¡ ã	25-32	8.115852e-5	8.317109e-5	1.071509e-4

ECS Real data analysis

Experiment setup





Not used in this paper

ECS Real data analysis (continued)

Experiment setup

- Receiving array: 60-element VLA, from 3m to 60m
- Source: locating at different depths z_s=5m, 20m, 40m, and different ranges r=5km, 10km, 20km and 30~40km
- Water depth: H=103m
- Signal forms: 1100-2000Hz PRN, 630Hz CW, 630Hz PCW, 1250-2500HZ LFM, and explosive sources

In our talk, only signals of 1100-2000Hz PRN at ranges of 5km and 10km, depths of 20m and 40m are used to estimated beam-averaged δ_n now.

ECS Real data analysis (continued)

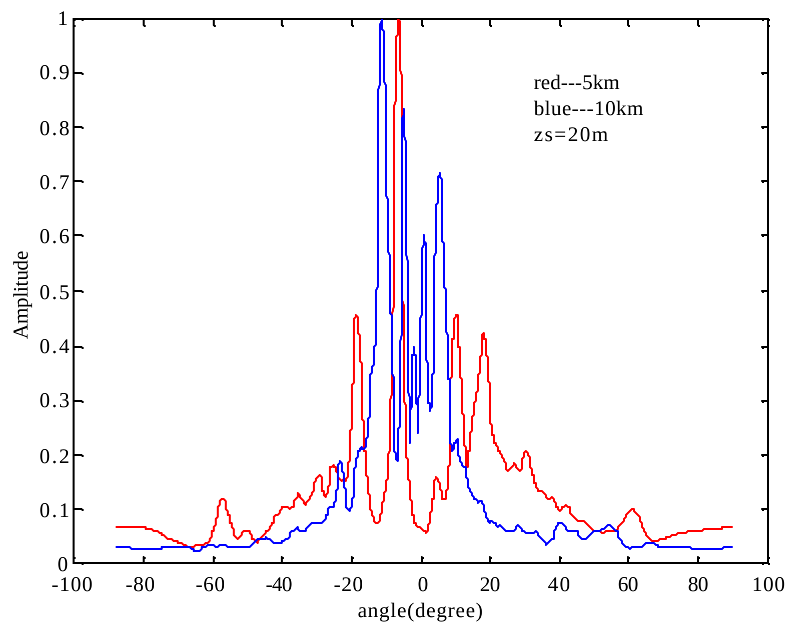


Fig.6 Vertical beam pattern with 20m source depth

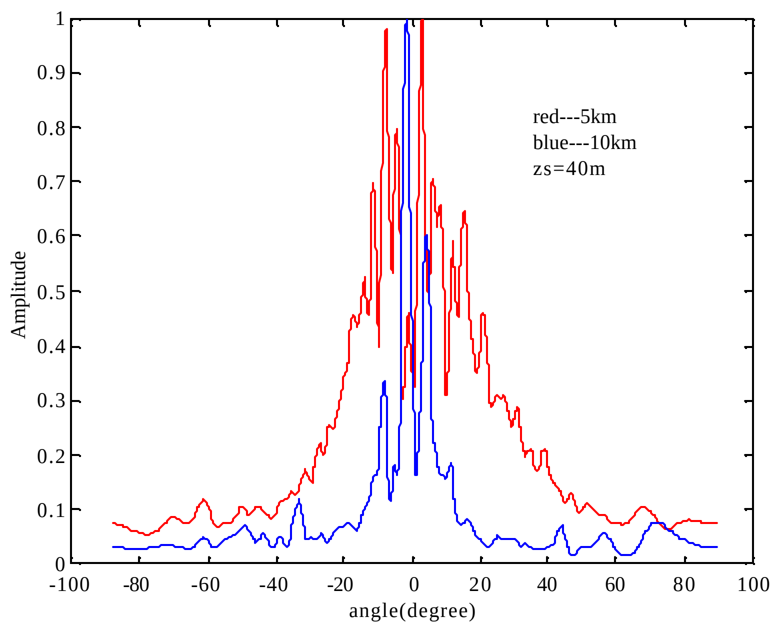


Fig.7 Vertical beam pattern with 40m source depth

Table 4 The estimated value of δ_n in real shallow waveguide (f=1340-1440Hz)

group	Center grazing angle	Group of modes	Estimated value of δ_n	
			r1=5km,r2=10km, zs=20m	r1=5km,r2=10km, zs=40m
1	2.3¡ ã	1-8	1.195583e-4	2.785835e-5
2	6.8¡ ã	9-16	2.447215e-4	1.224623e-4
3	11.5¡ ã	17-24	1.853596e-4	1.175435e-4
4	16.2¡ ã	25-32	2.953209e-4	1.934406e-4

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Summary

- If the intermode sum can be ignored, the beamformer output spectrum of two different ranges can be used to extract beam-averaged modal attenuation coefficient.

- When vertical beamformer is performed in a narrow band not in single tone, the intermode sum can be reduced effectively, as proved by the numerical examples, but it is still large, should be decreased further.

- From numerical simulation and ECS real data analysis results, we should extract beam-averaged model attenuation coefficient from data collected by longer VLA covered all water column in a broader band.

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Thank you!